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TELECOMMUNICATIONS RECEIVERBackground to the Invention

The present invention relates to a telecommunications receiver employing a new direct sequence code division multiple access (DS-CDMA) architecture which allows the use of fast adaptive algorithms.

Two adaptive algorithms are commonly in use, the LMS and RLS Algorithms^{1,2,3} and these are described in Appendix I.

The least mean square (LMS) algorithm (and the closely related normalised least mean squares (NLMS) algorithm) is a stochastic gradient algorithm which has only one parameter, the step size μ . The LMS algorithm is computationally simple but its convergence rate is slow and highly dependent on the properties of the input signal, more specifically on the eigenvalue ratio of the autocorrelation matrix. When many elements of the input signal are unknown, for example the channel in a mobile communications system, it is difficult to choose μ . The algorithm is numerically stable, but an inappropriate choice of μ can cause instability. In high noise conditions, the eigenvalue ratio of the autocorrelation matrix is low and this can help with convergence.

The recursive least squares (RLS) algorithm is computationally much more complex, but has much faster convergence than the LMS algorithm. It has two parameters, the forgetting factor λ and the initial diagonal matrix term δ . The forgetting factor is set appropriate to the rate of change of the autocorrelation of the input signal. The diagonal term has little effect on the algorithm once converged, but does affect the size of internal variables within the algorithm during initial convergence. The RLS algorithm is usually considered converged within a number of iterations equal to twice the filter length, which is generally much faster than the LMS algorithm. The RLS

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algorithm can become numerically unstable when the autocorrelation matrix of the input signal is close to being a singular matrix.

There are a few much less common adaptive filter algorithms and the use of these algorithms has been found desirable. The fast a-posteriori error sequential technique (FAEST)^{5,6} algorithm and its stabilised version the SFAEST⁷ which are also described in Appendix I, have a convergence rate close to the RLS algorithm but complexity close to the LMS algorithm. They do however impose an additional constraint: the input signal must have a shift invariant property. The shift invariant property simply means that the input signal must be the same as the input signal on the previous iteration shifted on by one sample, with only one new sample. This property is not satisfied by the conventional architecture for a minimum mean square error (MMSE) receiver for a DS-CDMA system⁸. The numerical stability of the FAEST algorithms is not as well understood as for LMS and RLS, but in practice the SFAEST algorithm seems to remain stable for a sufficiently long period of time for the purpose proposed here. The Fast Newton algorithm (see Appendix I) is an algorithm which can simplify the calculation of any of the above adaptive filter algorithms if the input signal can be modelled as an autoregressive filter with order less than is assumed by the above filters.

The conventional architecture for the uplink and downlink of a DS-CDMA system with an adaptive filter receiver is shown in Figure 1. In this architecture, the training of an adaptive FIR filter 1 of length $N+P-1$ chips (N being the number of chips per data bit and P the total number of chips in the code) is done at the bit rate, using an adaption error found by the algorithm to be the difference between data from a particular user and a sampled estimate of the data from the output of the filter 1, i.e. the filter has an effective training path ETP. The contents,

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of the filter 1 change completely from one iteration thereof to the next. This means that convergence is slow and it is not possible to use the FAEST or SFAEST algorithm because the shift invariance property is not satisfied. With the 5 LMS algorithm, convergence is too slow and the time taken to reconverge when a user switches on or off is far too slow. This architecture does work reasonably well with the RLS algorithm, although convergence is still not very rapid and the computational complexity is very high.

10 Summary of the Invention

It is one aim of the present invention to provide a DS-CDMA receiver using an adaptive filter in which the convergence is rapid. It is another aim of the invention to allow the use of the less common adaptive algorithms which 15 has not hitherto been possible.

The present invention provides a direct sequence code division multiple access (DS-CDMA) receiver comprising an adaptive filter controlled by an adaptive algorithm for filtering data which has been multiplied by a spreading code 20 and filtered by a channel filter, the adaptive filter having a length appropriate to model the inverse of the channel filter, and a multiuser detector operating on the output of the adaptive filter.

The algorithm is preferably either trained using the 25 spread-multiplied signal of a desired user only, or from a composite signal which is the sum of the spread-multiplied signals of more than one, for example all, transmitting users. This means that the adaptive filter will be trained by new information at the chip rate of the code.

30 In a particular embodiment of the invention the fixed multiuser detector is of the minimum mean squared error (MMSE) type, but it may alternatively be of the zero forcing (decorrelating), Volterra, Radial Basis function, cancellation, near optimum or other decoding types.

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The algorithm can for example comprise the least mean squares (LMS) or recursive least squares (RLS) algorithm. However, because the adaptive filter of the invention satisfies the shift invariance property, the algorithm may
5 alternatively comprise the fast a-posteriori error sequential technique (FAEST) algorithm, the stabilised FAEST (SFAEST) algorithm, and the above algorithms or others may be used in combination with the Fast Newton algorithm.

Brief Description of the Drawings

10 In order that the present invention may be more readily understood, reference will now be made, by way of example only, to the accompanying drawings, in which:-

Figure 1 shows the conventional DS-CDMA architecture already discussed;

15 Figure 2 shows DS-CDMA architecture according to an embodiment of the invention;

Figures 3, 4 and 5 are graphs of simulation results, showing respectively the comparative convergence of the architectures of Figures 1 and 2, the relative convergence
20 rates of different algorithms using the architecture of Figure 2, and the bit error ratio (BER) results for the architecture of Figure 2;

Figure 6 schematically shows a DS-CDMA system with no channel model;

25 Figures 7 and 8 are graphs showing signal to noise performance of a Wiener filter calculated for 7 chip and 31 chip Gold codes respectively;

Figures 9 and 10 are graphs showing bit error rate (BER) performance of the Wiener filter calculated for 7 chip
30 and 31 chip Gold codes respectively;

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Figure 11 is a graph showing convergence properties of the LMS and RLS adaptive filters;

Figure 12 is a graph showing BER performance of the LMS and RMS algorithms after 1000 iterations allowed for convergence, compared with the Wiener optimal and a matched filter with no MAI;

Figures 13 and 14 are graphs plotting BER against number of active users in an AWGN channel and a stationary multipath channel respectively, all users being equal power and the spreading code length being 7;

Figure 15 schematically shows the construction of a received signal $Y(n)$;

Figures 16 a) to d) schematically show the structures of a matched filter, a parallel canceller using matched filters, a Wiener filter and a parallel canceller using Wiener filters respectively;

Figure 17 is a graph showing the BER performance of the filters shown in Figures 16 a) to d); and

Figures 18 a) to d) are graphs plotting simulated BER averaged over all users against number of users for four different signal to additive Gaussian noise ratios, with 60,000 data bits per user and a sequence length of 64.

Detailed Description of the Preferred Embodiments

Figure 2 shows DS-CDMA transmitter and receiver architecture comprising spreading means 2 respectively operated by each user in which a data signal from the user is multiplied by one of a set of spreading codes uniquely allocated to the respective user. The data is supplied to the spreading means at its bit rate and the code is input at its chip rate, there being N code chips for each data bit.